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EVAPORATION COOLING OF GLASS-MELTING FURNACES (A REVIEW)

N. I. Min'ko,[1] Yu. S. Zaitsev,[1] N. N. Zaitseva,[1] R. L. Bilinskii,[1] and Yu. M. Shershnev[1]

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This paper presents comparative characteristics of evaporation cooling for glass-melting furnace walls, as compared with air and water cooling. The expediency of using evaporation heating for the purpose of energy saving is demonstrated.

Production of glass involves substantial consumption of fuel and materials. That is why the contemporary situation in the glass industry requires energy-saving, cost-effective, and environment-friendly technologies. The main part of electricity and material resources in the production of glass articles is consumed by the glass-melting furnace which consumes 40 – 70% of total energy, depending on the type of product, and up to 20 – 30% materials.

The efficiency of a glass-melting furnace largely depends on its energy consumption (mostly gas or liquid fuel) per product unit. According to the available data [1], the furnace efficiency in sheet glass production is 30%, for container and household glass it is 20 – 25%, and 20 – 25% for technical glass.

A promising field directed to saving of power and material resources and extension of service life of glass-melting furnaces is upgrading of furnace components and furnaces on the whole.

It is possible to reduce heat losses in glass-melting furnaces via the brickwork with waste smoke gases, as well as utilize this heat. Various designs and materials are used to decrease heat losses through the brickwork, which involves additional expenses [2 – 4].

The campaign of continuous furnaces in our country lasts 3 – 6 years, whereas this period abroad amounts to 8 – 10 years, and in the production of polished sheet glass, to 10 – 12 years [5]. Due to deterioration of melting tank walls, glass-melting furnaces have to be stopped for cold repairs, although the bottom and the roof are yet in good state. It is possible to extend the service life of the walls using expensive high-quality materials, but with intensive glass-melting process, it is impossible to significantly increase the period between repairs. In the second half of the furnace campaign, due to the wear of the inner surface of the tank wall at the glass melt level, the outer surface temperature increases up to 300 degrees and more, which creates hard labor conditions for the operating personnel. Moreover, a decrease in the wall thickness creates the risk of the glass melt erupting from the furnace [6, 7].

There are various methods for increasing the service reliability of furnaces. In particular, the wear of refractory brickwork can be reduced by air fanning of the furnace (USSR Inventor's Certif. Nos. 1041525 and 1232654; Japan patent application 62-40294) [8]. Air cooling gained wide acceptance in glass melting; however, it does not provide a radical solution of the problem; the life cycle of glass-melting furnaces remains short, and the labor conditions are not improved. The consumption of air needed for cooling of a glass-melting furnace of capacity 60 – 70 tons/day amounts to 70,000 m^3/h with engine electricity consumption of 60 kW. Furthermore, the hot waste fan air penetrates into the working area and is not recaptured. The performance of glass-melting furnaces using air cooling of the walls indicated that to a certain extent it delays the erosion of refractory blocks but turns out to be unreliable and inefficient under strong heating of the brick lining.

The insufficient effect of air chilling motivated the use of water cooling for glassmelter walls. The first data on the use of water-cooled tank furnace walls date back to 1929, when water-chilled coil pipes were used for the first time in certain areas of the glass-melting furnace at the Krasnousol'skii Glass Works, which extended the furnace campaign by 6 months [9]. In the case of water chilling, the chilled ele-

[1] Belgorod State Technological Academy of Construction Materials, Belgorod, Russia; Domna Company, Kharkov, Ukraine; Steklomash Joint-Stock Company, Orel, Russia.

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ments are installed on the outer side of the brickwork, and the whole chilling system starts working after the furnace starts operating. When the water cooling system is used, a lining slag layer made up by solidified glass is formed at the inner side of the brickwork. This operating mode is preserved during the whole life cycle of the furnace, and the refractory material contacts with the fluid glass melt to a lesser extent, which decreases the lining wear.

If chillers are installed without a protective brick layer or if we assume that the wall brickwork will get fully destroyed by the end of the furnace campaign, the specific density of the heat flow on the chiller surface can achieve 150 kW/m^2. With the usual water cooling and a small flow rate (0.1 m/sec) of water, the convective heat transfer coefficient on the cooled surface attains the value of 1000 W/(m$^2 \cdot$ K). In this case, local water boiling occurs inside the layer adjacent to the wall, and scale is intensely formed. Under jet chilling, the speed of water jets poured on the chilled surface exceeds 1.0 m/sec, and the coefficient of heat transfer from water to the wall reaches 2500 W/(m$^2 \cdot$ K). In such conditions, no local boiling takes place near the cooled wall surface, and scale precipitation is delayed. Reliable functioning of the water chilling system requires substantial consumption of technical water, to ensure the self-purifying speed of the water flow.

There are various designs for water chilling of glass-melting furnaces (USSR Inventor's Certif. Nos. 1039903, 1204585, and 1325022) which have their advantages and disadvantages. Since water takes away a certain amount of heat in glass melting, this heat needs to be compensated by combustion of an additional quantity of fuel.

The next step in improving the work of glass-melting furnaces and extending the brickwork life cycle is the use of evaporative cooling. The essence of evaporation cooling consists in the fact that the technical water used for chilling is converted through regeneration to chemically pure water which takes off heat from the tank wall as the result of boiling. This technology provides for scale-free operation and the heat lost via chilling is recovered by means of utilization of steam regenerated by the evaporation cooling system.

Evaporation cooling was passed on to the glass industry from ferrous metallurgy. The first data on the use of evaporation cooling of glass-melting furnaces date back to 1957, when the Institute of Gas Usage of the Ukrainian Academy of Sciences together with the Avtosteklo Konstatinovka Works implemented evaporative cooling of a small tank furnace for melting highly siliceous glass, and then together with the Zaporozhe Glass Works introduced this technology to a flux-melting furnace. It should be noted that the evaporation cooling design was performed using the high-precision measurement method and the simplified method developed by Giprostal' [10].

The Krasnoe Znamya factory (Vladimir Region) for several years operated a furnace with a horseshoe-shaped flame direction for clear glass melting. The life-cycle duration did not exceed 9 months due to deterioration of the refractory elements, especially the tank walls. Air chilling was not effective and after recurrent glass leakage through the walls, the furnace was equipped with the evaporative cooling system [11].

The chilling systems of the lateral tank walls, the loading hopper, and the furnace neck were converted to evaporative cooling. The steam output of the evaporative equipment increased from 0.5 ton/h in the beginning of the life cycle to 1.5 tons/h at the end. The resulting steam pressure was 0.6 – 0.8 MPa. The vapor was utilized for the needs of the factory.

The main performance parameters of the furnace after 14 months of the second life cycle were as follows: steam output 0.6 ton/h, electricity consumption 10 kW $\cdot$ h (instead of 120 kW $\cdot$ h with air cooling), the economical effect 50,000 rub per year (in 1989 prices), and the repayment of the evaporating cooling equipment less than 1 year.

The campaign of the glass fiber furnace at the Valmiere Glass Factory (Latvia) used to be 18 months, and after the installation of evaporation cooling, the furnace life cycle exceeded 34 months [12].

Main furnace parameters of furnace using evaporation cooling

Bottom surface area of melting tank, m^2	31
Heating surface area, m^2	25
Steam output, tons/h	0.9
Steam pressure (excessive), MPa	0.75
Volume, m^3	
water	5.0
steam	2.5
Circulation cycles per hour	2.5

Under air cooling, the cold fanning air used to penetrate inside the furnace, which caused an increase in fuel consumption. After air chilling was replaced with evaporation chilling, the fuel consumption decreased by 7% on the average, and besides, additional steam arrived at the steam system of the factory (0.9 ton/h) [12].

The Merefyanskii Glass factory also replaced air chilling by evaporative chilling. The chilling of the tank walls of glass-melting furnace No. 3 intended for aluminoboron-silicate glass melting used to be performed by air fanning. The furnace campaign lasted 14 months.

Main parameters of the furnace

Bottom surface area of melting tank, m^2	55.2
Natural gas consumption on heating, m^3/ton	1000
Fan efficiency, m^3/h	12,000
Fan engine power, kW	45

An emergency stop occurred in the furnace in August 1992 due to the break of the accumulating tank wall. The company decided to equip the tank walls of glass-melting

furnace No. 3 with an evaporation cooling system. The design and manufacture of the chilling equipment, as well as the installation and start-up of this system, was performed by the Domna Company.

The furnace functioned for 7 months and was stopped for the lack of demand for the product (caused by the industrial slump in the country). The steam generated by the evaporation cooling system was used by the company for technological needs. According to the available data, the glass-melting furnace is in a good state.

The evaporation cooling of glass-melting furnaces is efficient, since it ensures reliable scale-free cooling, normal labor conditions, and utilization of the heat lost as the result of the furnace cooling. In the case of evaporation cooling, the steam generated by the factory boiler house is replaced by the steam generated by the evaporation system, which reduces fuel consumption in the boiler house. If the boiler efficiency is higher than that of a glass-melting furnace, the excessive fuel consumption in the furnace exceeds the amount of fuel saved in the boiler house. This excessive fuel consumption in air evaporation decreases, compared to water cooling, and cooling becomes economically more effective. By estimation, in the case of using evaporation cooling, an increase in thermal losses up to 10% is economically justifiable (i.e., the chilling of the lateral walls is economically justifiable). Besides, an improvement in working conditions is accomplished [13].

Several variants of evaporative cooling for glassmelter walls have been designed, which extend the service life of refractory brickwork. These chiller designs have been tested both at steel-and-iron works and in the glass industry. The inter-repair period of a blast furnace used to be 5 – 6 years, and after installing evaporation cooling it was extended to 10 – 12 year. The chillers proved to be resistant and reliable. They were used to equip furnaces Nos. 1 and 2 of the Donetsk Steel-and-Iron Works, blast furnaces Nos. 3 and 4 of the Mariupol Steel-and-Iron Works, furnaces Nos. 3 and 4 of the Steel-and-Iron Works at Azovstal' (Mariupol), furnaces Nos. 5 and 6 of the Yenakievo Steel-and-Iron Works etc., as well as glass-melting furnace No. 3 of the Merefyanskii Glass Works [13].

It should be noted that data on thermal conditions of heat losses of cooled elements through cooling water can be obtained by individual investigation of particular glass-melting furnaces equipped with evaporation cooling. In order to further improve the glass-melting technology through installation of evaporation cooling, which extends the life cycle of furnaces, decreases heat losses, and improves working conditions, it is necessary to develop specific individual chiller designs for each furnace.

The service of metallurgical and glass-melting furnaces with evaporation cooling revealed the high reliability of the system, since it is based on natural water circulation and therefore can work for 1 h without water supply. The system is functional even in the case of complete eroding of refractory material in a certain area of the tank. In this context, the tank lining can be made of wall beams 150 mm thick instead of beams 250 – 300 mm thick.

The evaporation cooling system makes it possible to solve the problem of utilization of waste furnace gases using convective heat exchangers which can be inserted as individual components of the evaporation cooling system.

REFERENCES

1. G. M. Matveev, V. V. Mironov, E. M. Raskina, and K. E. Taraskevich, "Energy saving in glass melting," *Steklo Keram.*, No. 11, 10 – 11 (1998).
2. Yu. K. Kuznetsov, L. Ya. Levitin, E. P. Markov, et al., "The effect of thermal insulation of the melting tank bottom on glass melt heat exchange," *Steklo Keram.*, No. 6, 8 – 9 (1986).
3. A. S. Bokova, Yu. I. Murav'ev, and A. D. Al'ter, "Main design solution intended for fuel saving in glass-melting furnaces," *Steklo Keram.*, No. 3, 5 – 6 (1982).
4. O. N. Popov, L. E. Krasnyi, and M. Ya. Bogomol'nyi, "Experience of using heat insulation in glass melting furnaces in the USSR and abroad," *Steklo Keram.*, No. 3, 9 – 11 (1982).
5. A. A. Shaeffer, *Allgemeine Tehnologie des Glasses*, Erlangenr (1995).
6. O. N. Popov, V. E. Mancvich, and G. P. Lisovskaya, "Analysis of thermal operation of the glass-melting furnace," *Steklo Keram.*, No. 5, 6 – 7 (1981).
7. M. N. Kucheryavyi, O. N. Popov, V. T. Selyanko, et al., "Extension of the service life of refractories in tank furnaces for melting container glass," *Steklo Keram.*, No. 9, 5 – 6 (1983).
8. O. N. Popov, R. Z. Fridkin, and Z. T. Mamedov, "Evaluation of the efficiency of evaporation cooling in glass-melting furnaces," *Steklo Keram.*, No. 2, 8 – 10 (1983).
9. D. P. Orlov, "Water cooling of tank furnaces," *Steklo Keram.*, No. , 1, 11 – 13 (1929).
10. N. A. Zakharikov, A. I. Rozhanskii, and V. A. Sukhovei, "Evaporative cooling of tank furnace walls," *Steklo Keram.*, No. 9, 7 – 12 (1961).
11. E. I. Shipov, M. Ya. Khinkis, S. V. Levitin, et al., "Evaporation cooling of the glass-melting furnace tank," *Steklo Keram.*, No. 11. 8 – 12 (1968).
12. A. A. Zeibots, "Evaporation cooling of the glass-melting furnace tank," *Steklo Keram.*, No. 7, 28 – 29 (1974).
13. Yu. S. Zaitsev and O. V. Filip'ev, *Evaporation Cooling of Glass-Melting Furnace Walls* [in Russian], Osnova, Kharkov (1993).